

Carbon-based Fuel Cell



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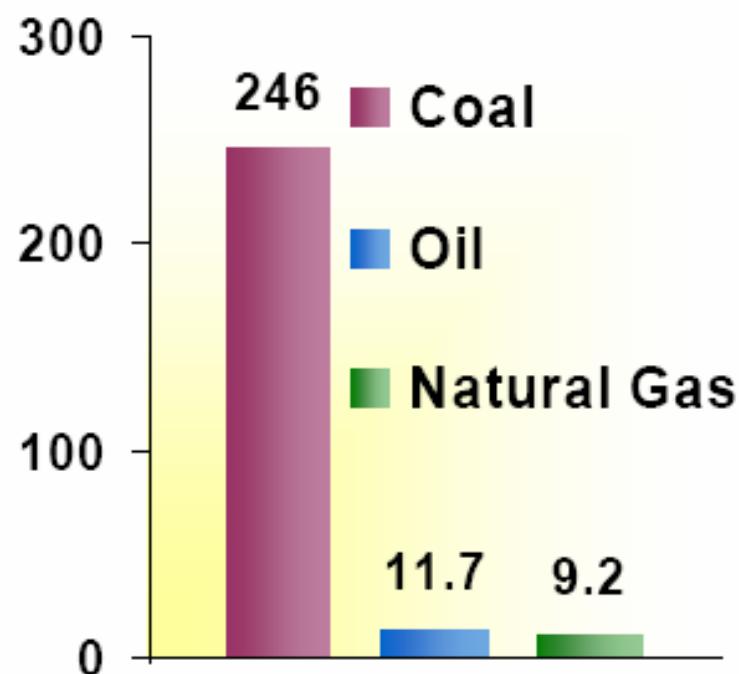
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Coal Is Important

- Abundant domestic reserves
- Low and stable prices
- Provide > ½ nation's electricity
- Future source of H₂

- Economic prosperity
- Energy security

U.S. Fossil Fuel Reserves/
Production Ratio
*Years Supply at
Current Production*



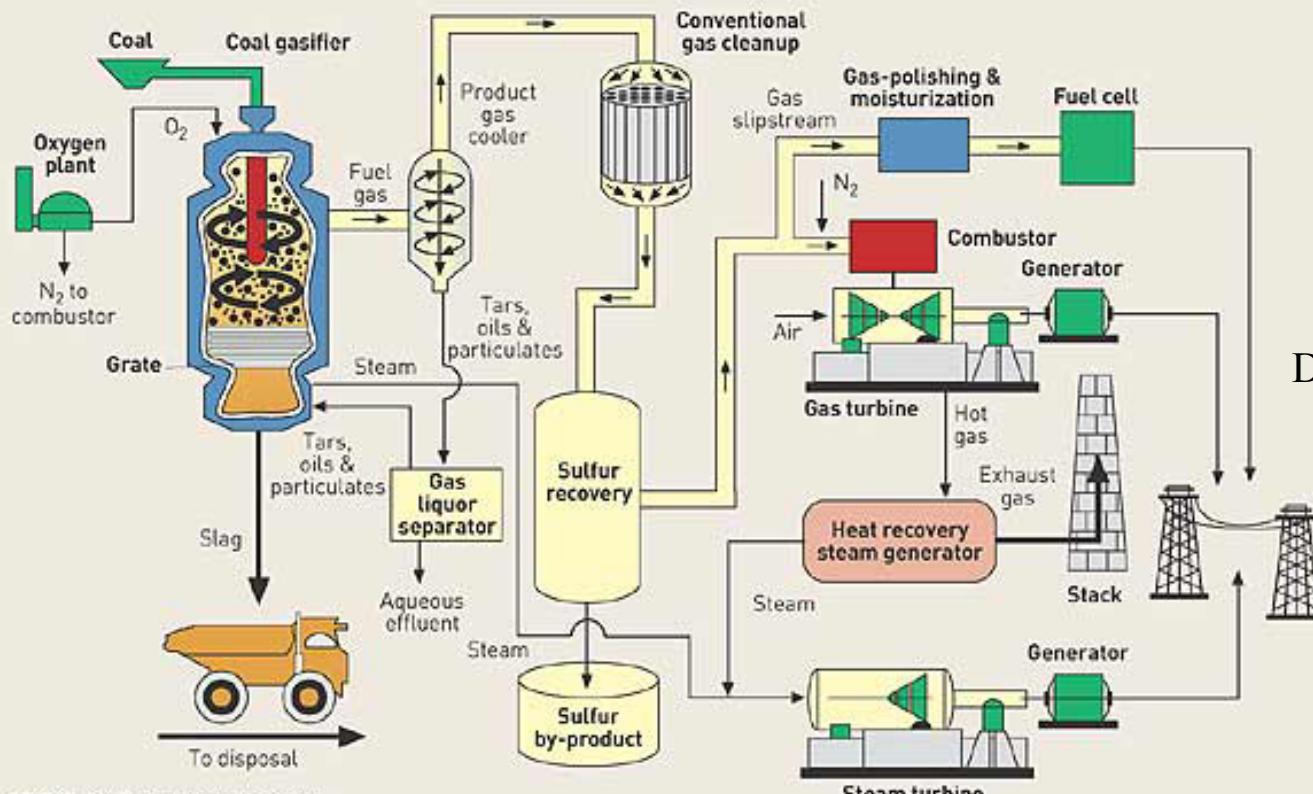
EIA- U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves: 2001 Annual Report,
November 2002; Coal: BP Statistical Review, June 2002, World Energy Council

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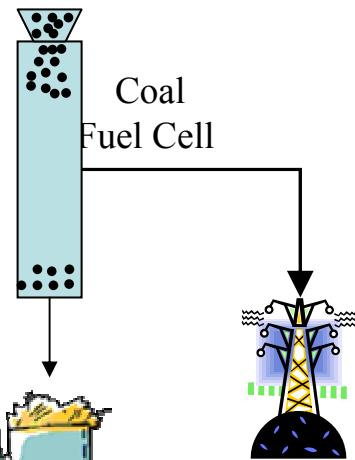
CLEAN COAL

Integrated gasification combined-cycle technologies like this one turn coal into hydrogen, and ultimately electricity with low emissions of SO_x , NO_x , and Hg and the potential to capture CO_2



SOURCE: Los Alamos National Laboratory

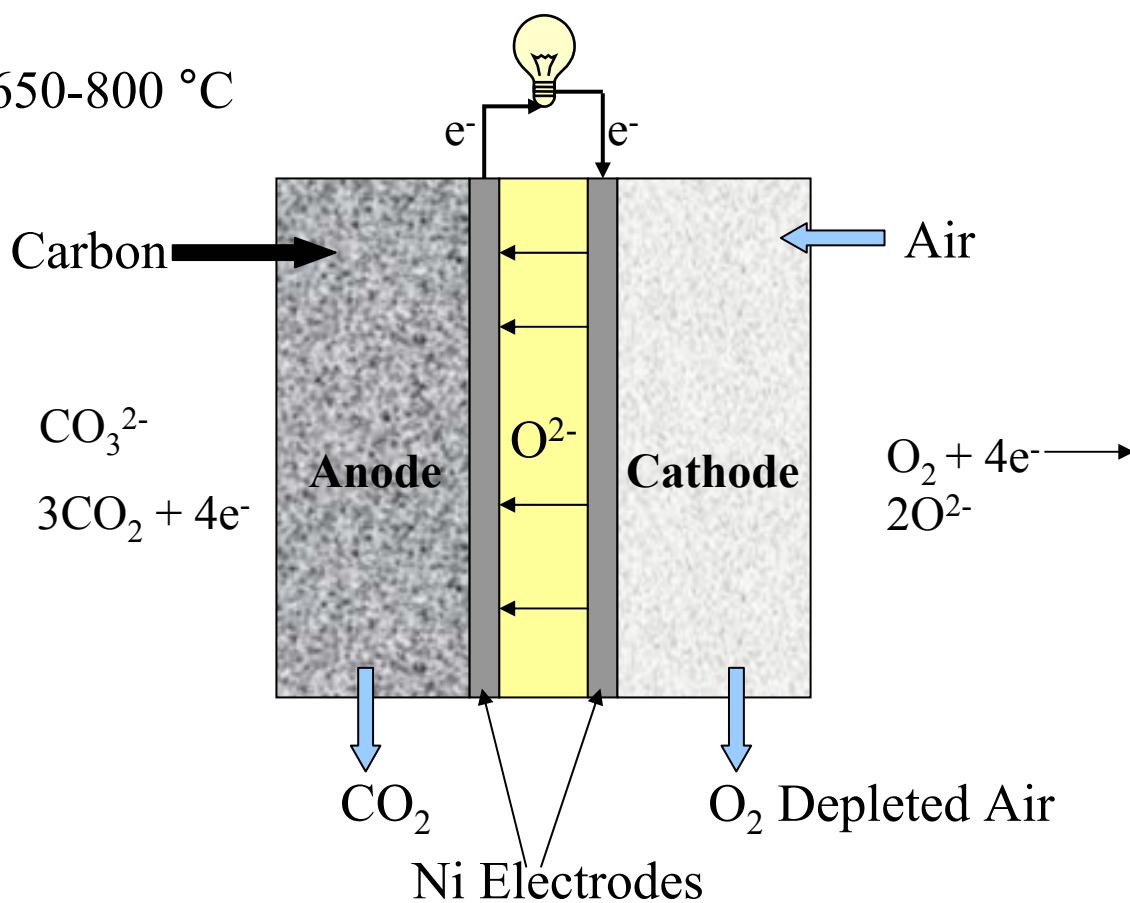
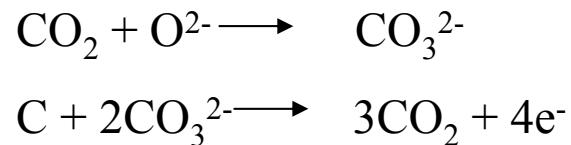
Disposal



Source: The University of Akron

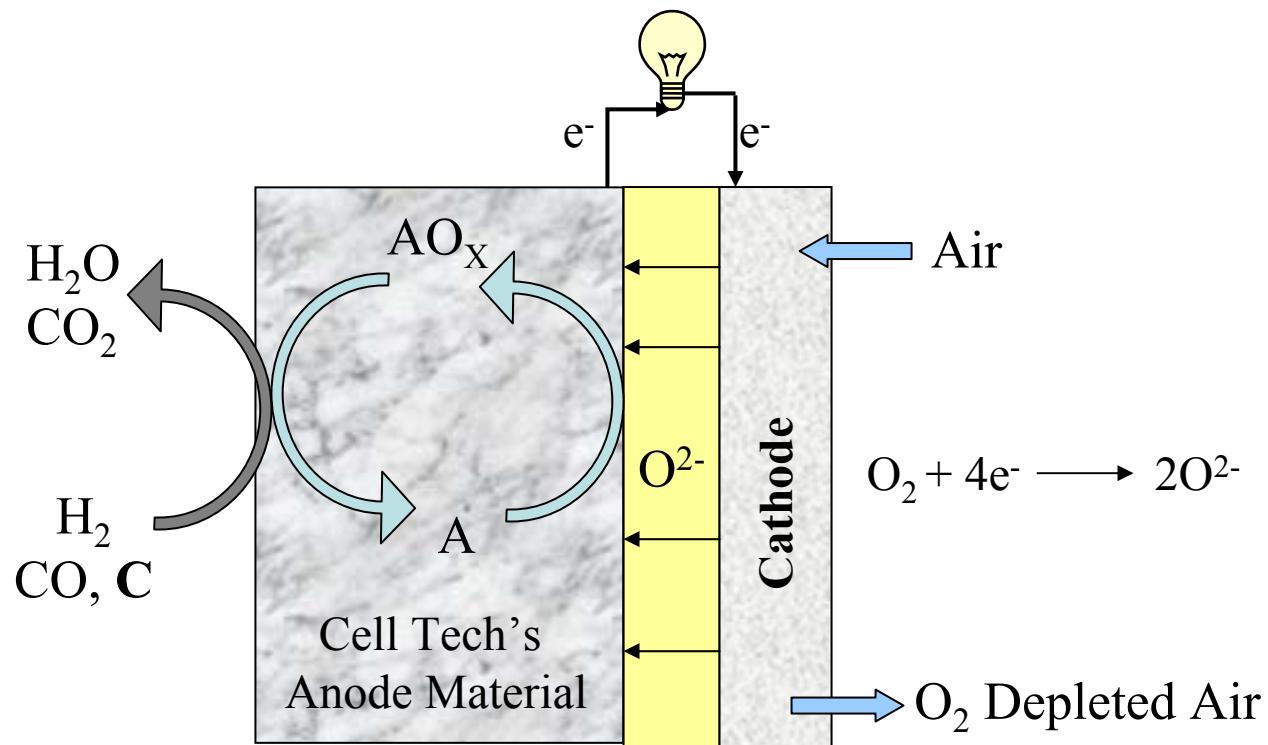
C-Fuel cell – Lawrence Livermore

Operating T = 650-800 °C

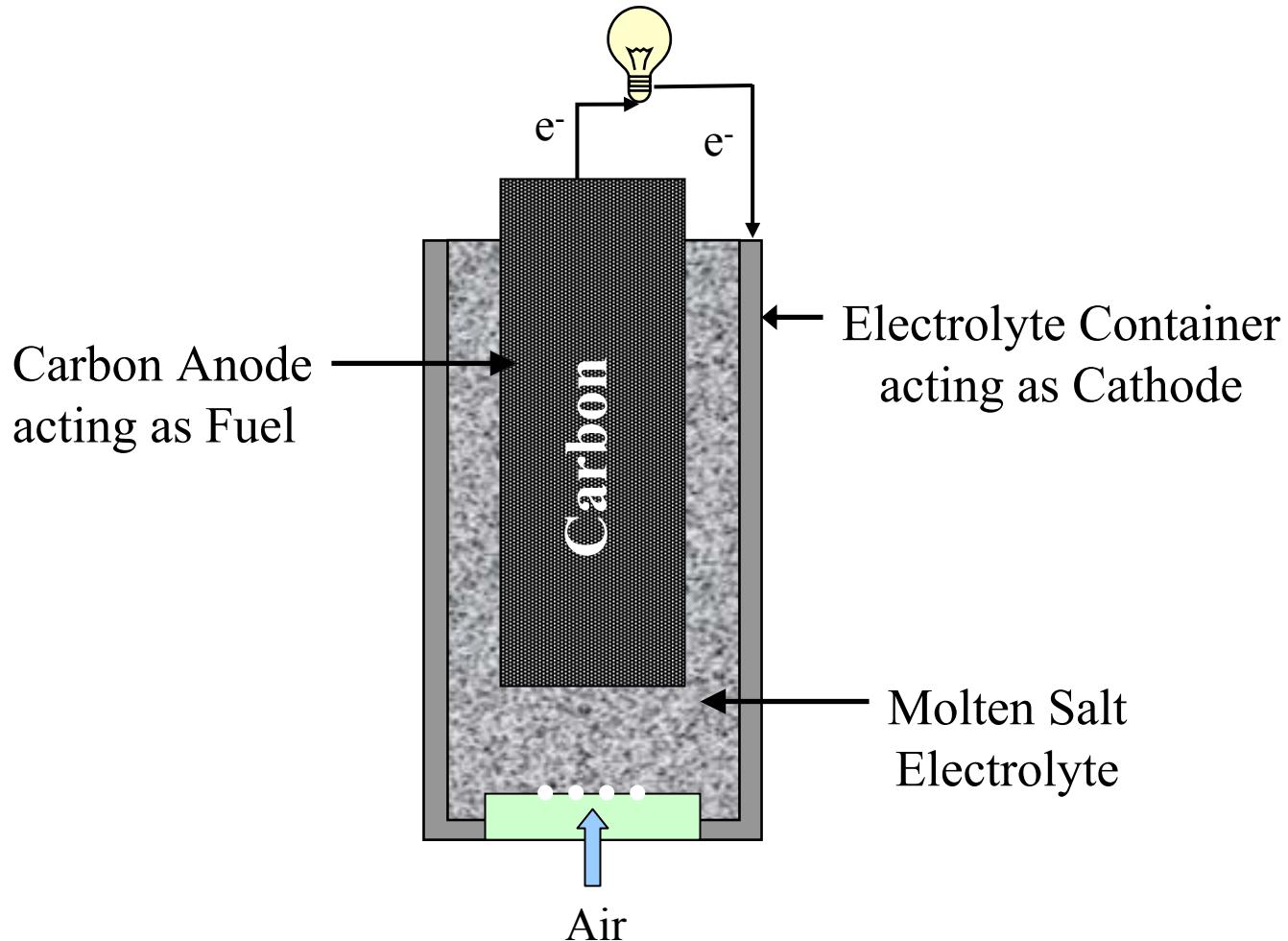


- High fuel cell efficiency: 80% of HHV based on $\Delta H^\circ_{298} = 32.8 \text{ MJ/kg-C}$
 - Electrolyte is unconsumed and invariant
 - Fixed C, CO₂ activities \Leftrightarrow full conversion of C
 - Actual anode and cathode reactions may involve CO₃²⁻ ion

CellTech's C-Fuel cell

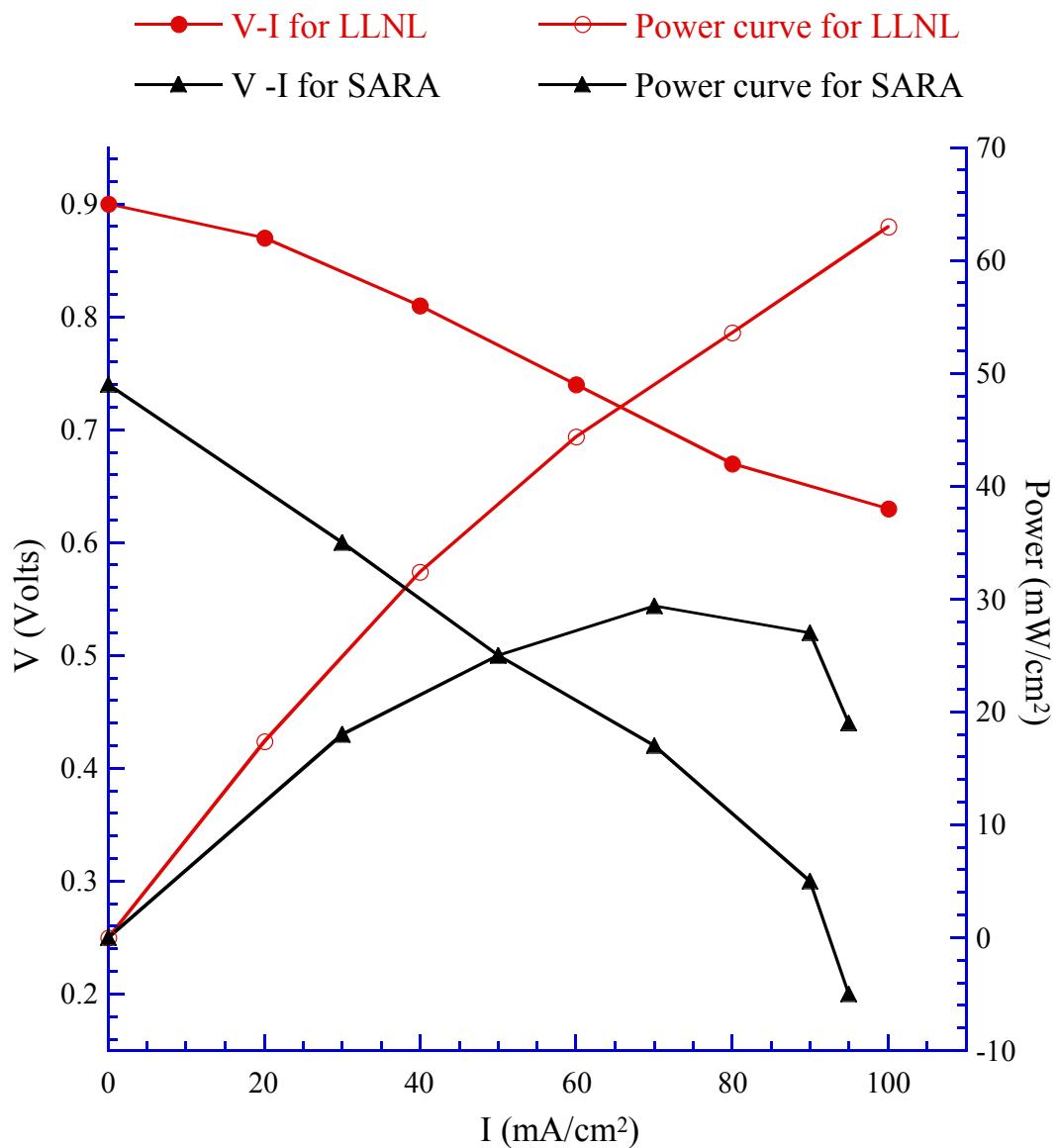


SARA's Direct C-Fuel Cell



US Patent No. 6,200,697

Comparison of SARA and LLNL C-Fuel Cell



Efficiency of Fuel Cells

Fuel	Theoretical limit = $\Delta G(T)/\Delta H_{std}^o$	Utilization efficiency, μ	$V(i)/V(i=0) = \varepsilon_v$	Actual efficiency = $(\Delta G/\Delta H_{std}^o)(\mu)(\varepsilon_v)$
C	1.003	1.0	0.80	0.80
CH ₄ ^a	0.895	0.80	0.80	0.57
H ₂	0.70	0.80	0.80	0.45

Efficiency of a fuel cell or battery is defined:

= (electrical energy out) / (Heat of combustion (HHV) of fuels input)

= [theoretical efficiency G/H][utilization fraction μ][voltage efficiency ε_v]

= $[\Delta G(T)/\Delta H^o][\mu][V/V^o] = [\mu][nFV]/\Delta H^o$

--where $\Delta G(T) \equiv - nFV^o \equiv \Delta H - T\Delta S$

Typical C/air efficiency is 80%

Must adjust for Energy Cost of Fuel Production

Objectives

Phase I

- Determine the feasibility of generating electric power from coal in solid oxide fuel cells.
- Compare the performance of coal, coal gas, and methane fuel cells.

Phase II

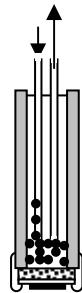
- Identify the lead catalysts (i.e., the catalysts which show a great potential).
- Use thin electrolytes to enhance the power density (mA/cm^2). .

Overall goal: bringing the innovative concept of the solid oxide C-fuel cell to the practical technology.

Fuel Cell Milestones



Dry CH₄ Fuel Cell and with D₂O reforming



Coal Fuel Cell Stockton Seam

Coal Gas Fuel Cell

Apr'03

May' 03

Oct' 03

Jan' 04

Feb' 04

Jun' 04

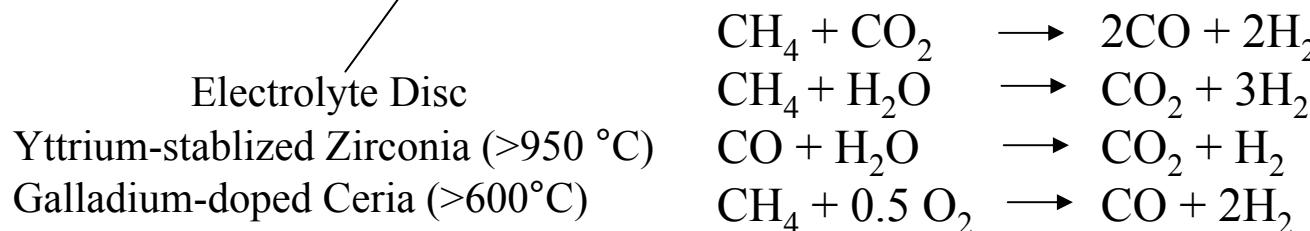
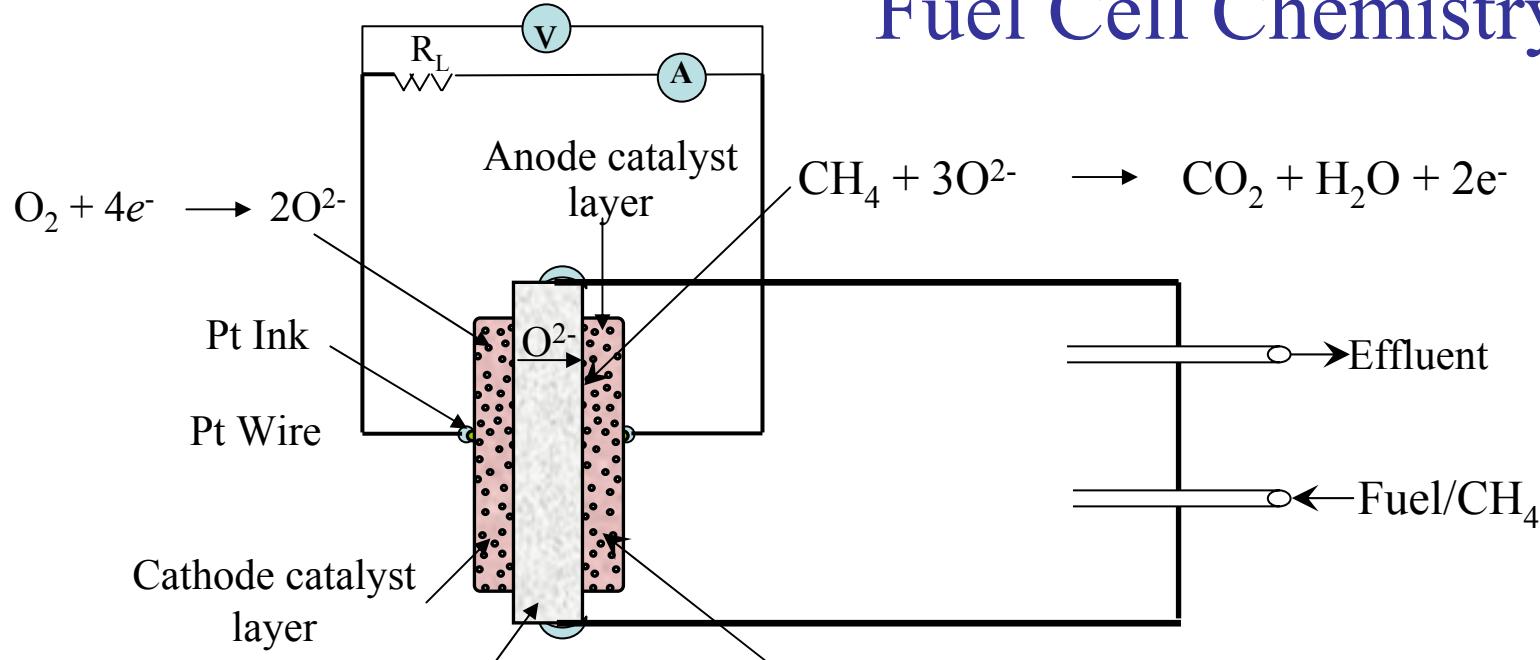


Activated C Fuel Cell

Ohio Coal # 5
110 mA/cm² @ 0.6 V

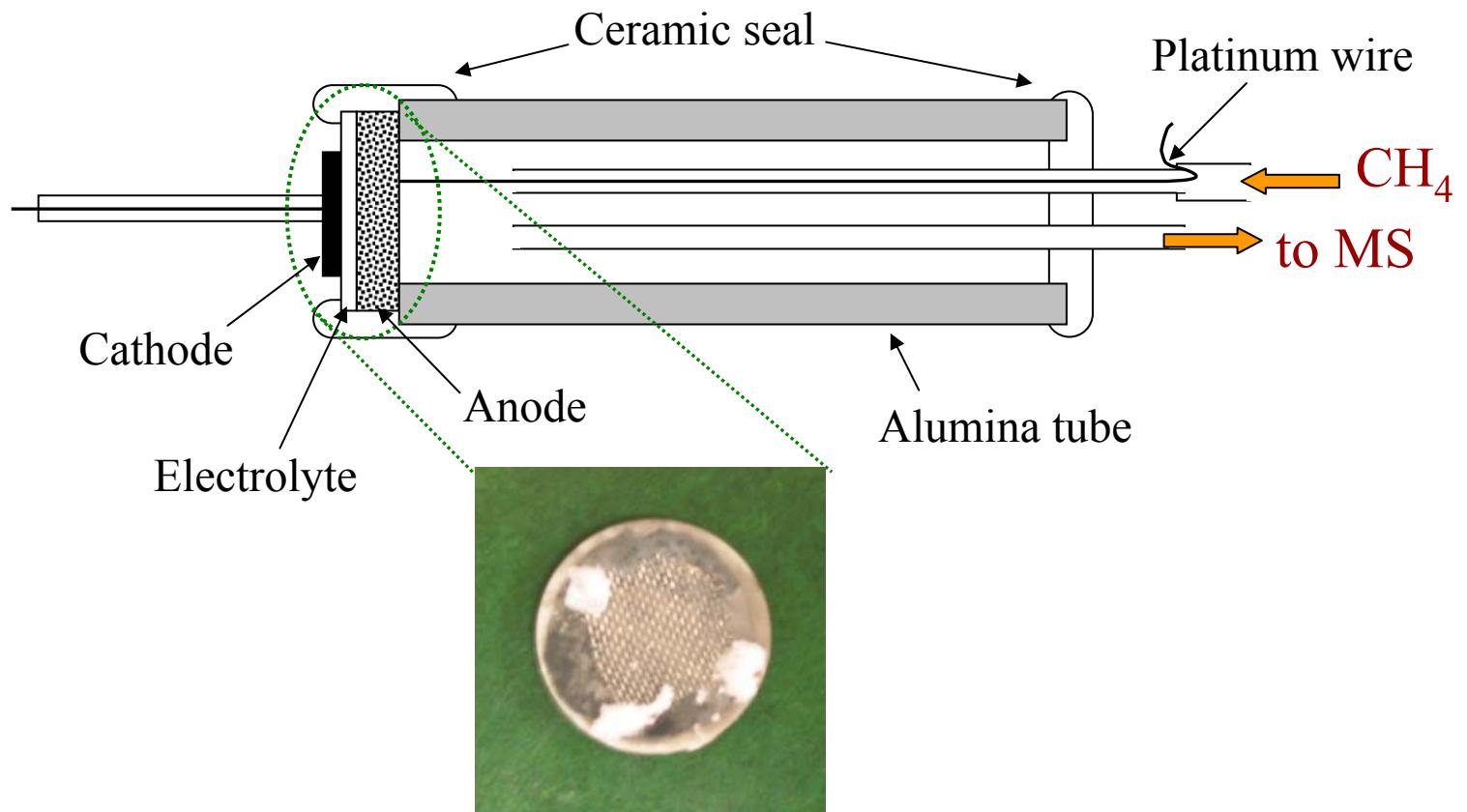
S-Tolerant CH₄/H₂/C₇H₁₆ Fuel Cell

Fuel Cell Chemistry

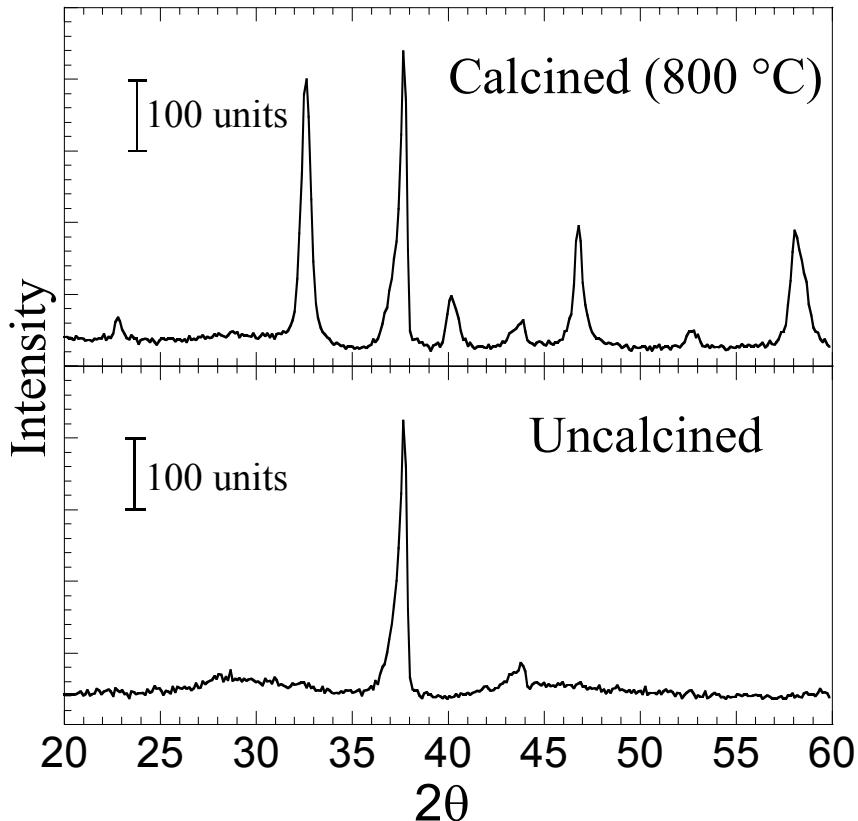


A	O_{ad}	Products	T (°C)
CH_4	$O_{ad} \rightarrow CO, H_2, CO_2, H_2O$		600-1200
C_nH_{2n}	$O_{ad} \rightarrow C_nH_{2n}O, CO_2, H_2O$		
C	$O_{ad} \rightarrow CO_2$		550-950

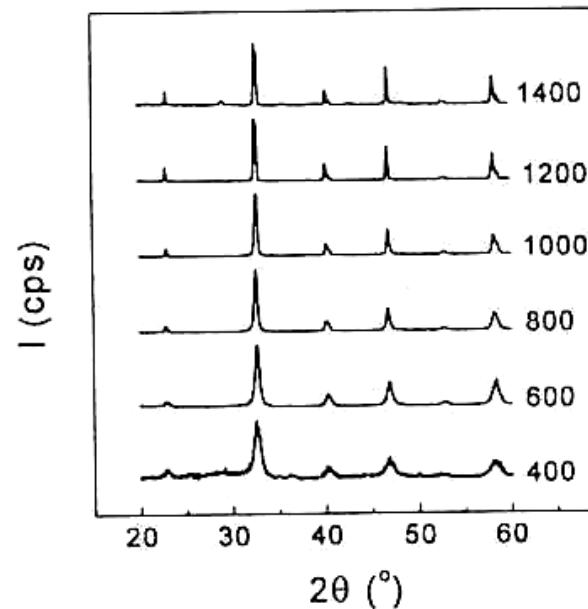
Fuel Cell Assembly



XRD Patterns of LSM



XRD Pattern of uncalcined LSMO
and LSMO calcined at 800 °C

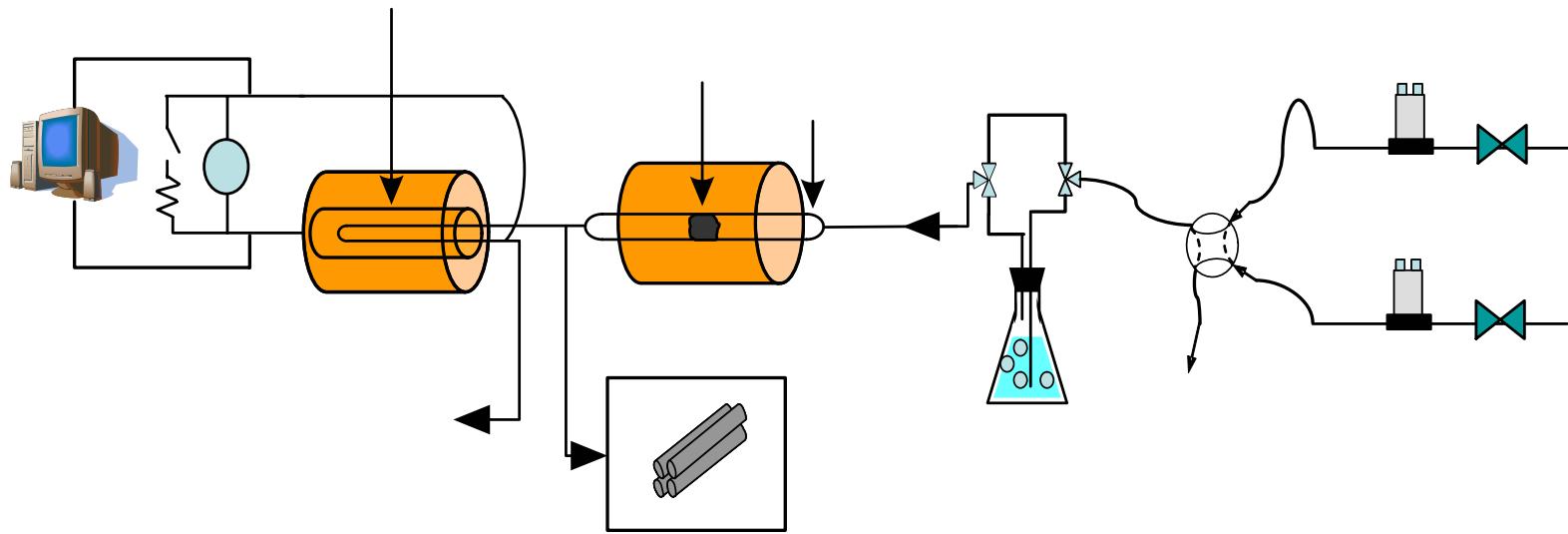


XRD patterns of LSMO
calcined at different
temperature.

Composition of Ohio Coal # 5

Table 2 Ohio Coal no. 5 (Sample PSOC-1517)			
PROXIMATE ANALYSIS		ULTIMATE ANALYSIS	
% Moisture as received	4.15	% Carbon	83.99
Dry % ash	4.80	% Hydrogen	5.50
Dry % volatile matter	37.98	% Nitrogen	1.88
Dry % fixed carbon	57.22	% Oxygen	8.63
SULFUR FORMS		CALORIC VALUE (BTU/lb)	14258
% Pyritic	0.70	% Organic	1.21
% Sulfate	0.01	% Total	1.92
		EQULIBIRUM MOISTURE (%)	7.98

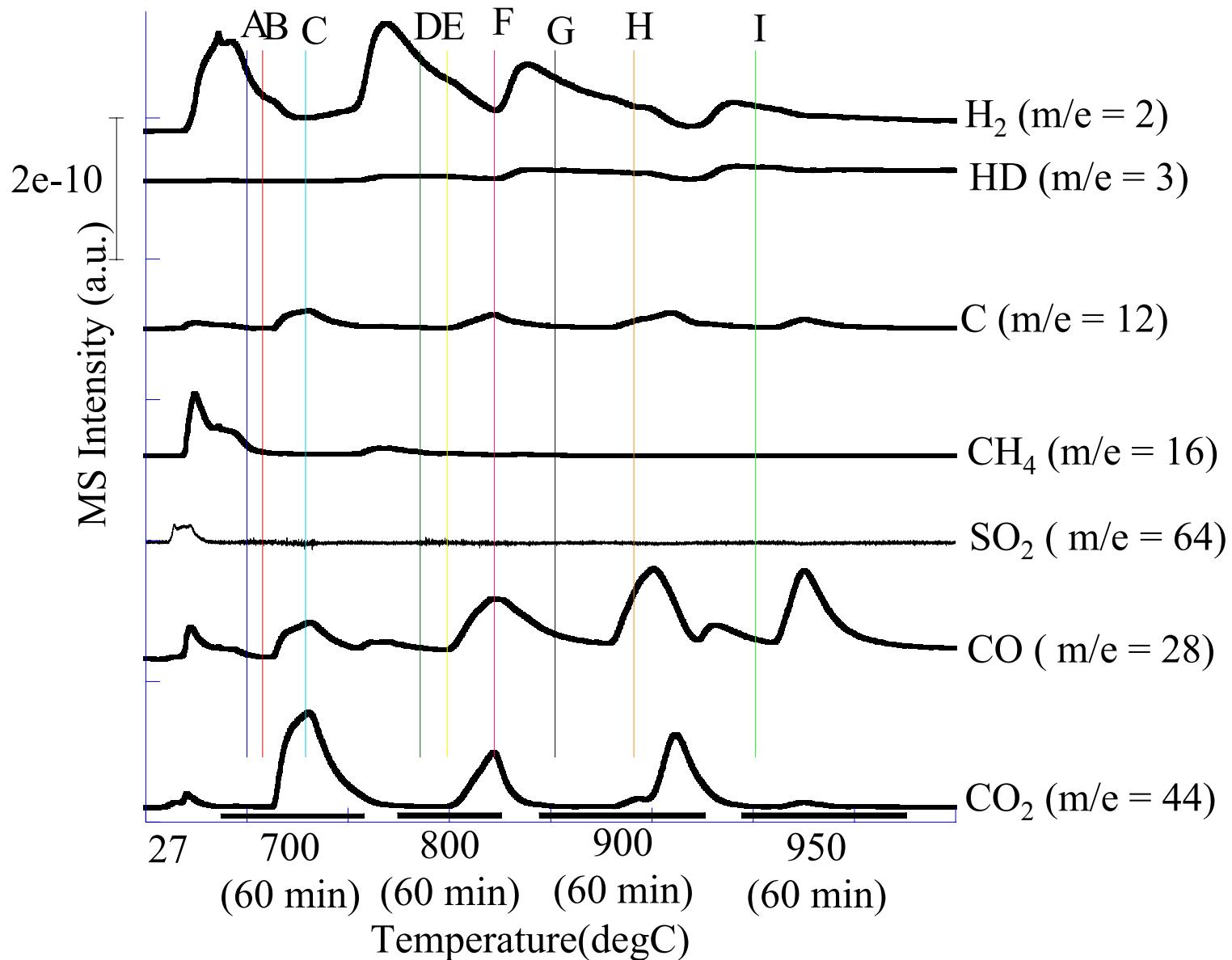
Coal Gas Fuel Cell



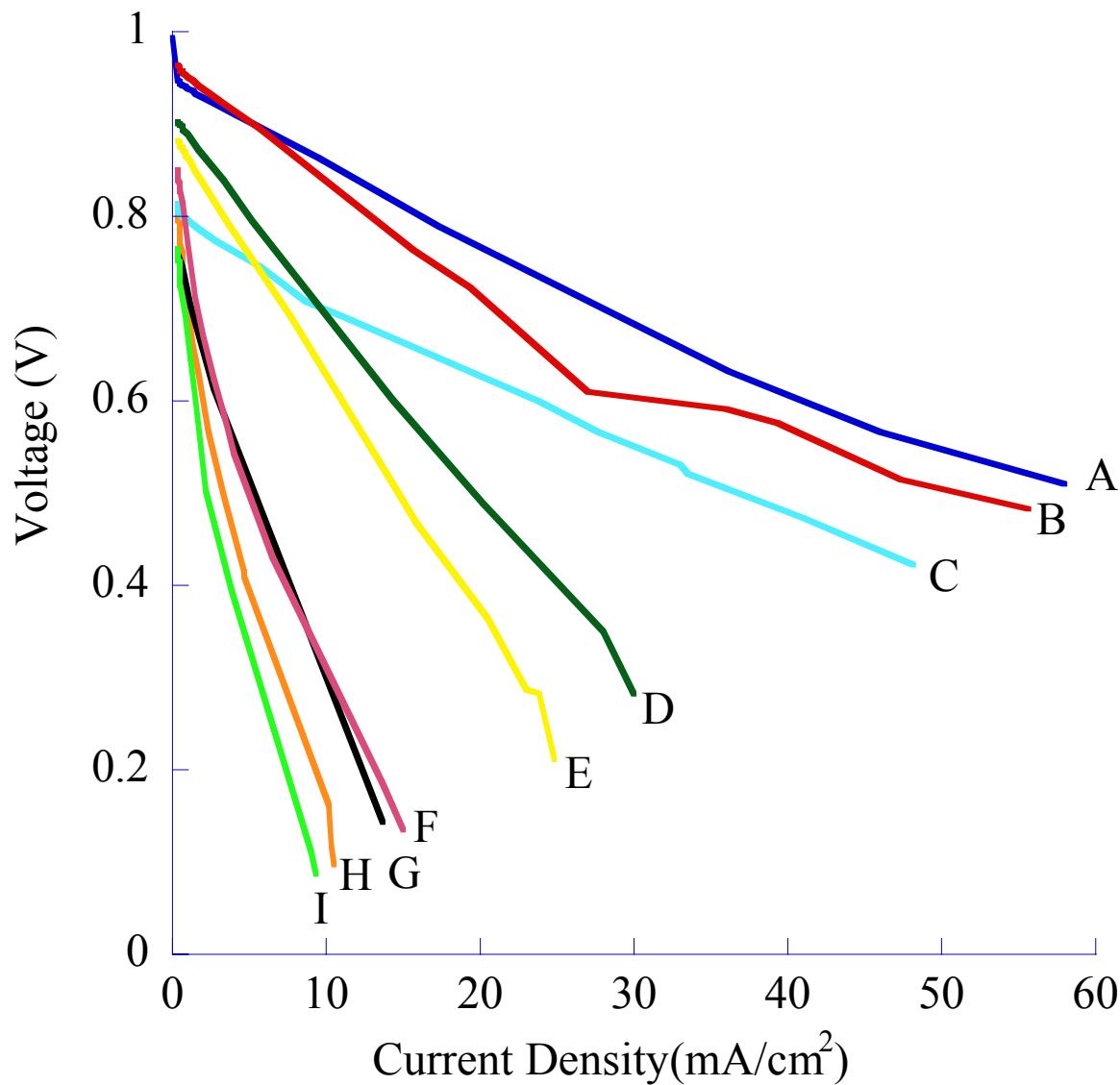
Labview

Fuel cell

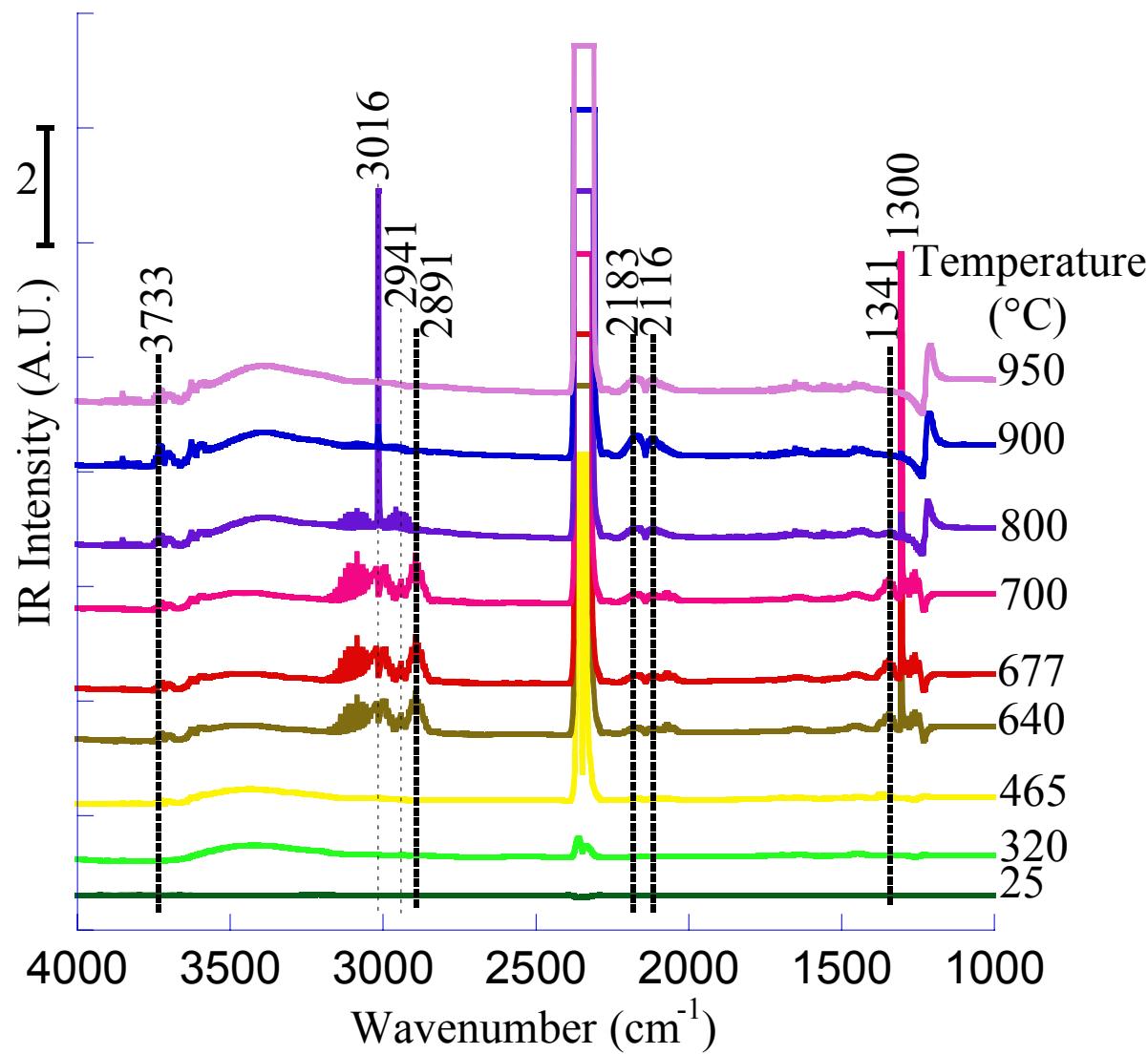
MS Profiles during Gasification of Ohio Coal # 5



V-I Curves of Coal Gas Fuel Cell

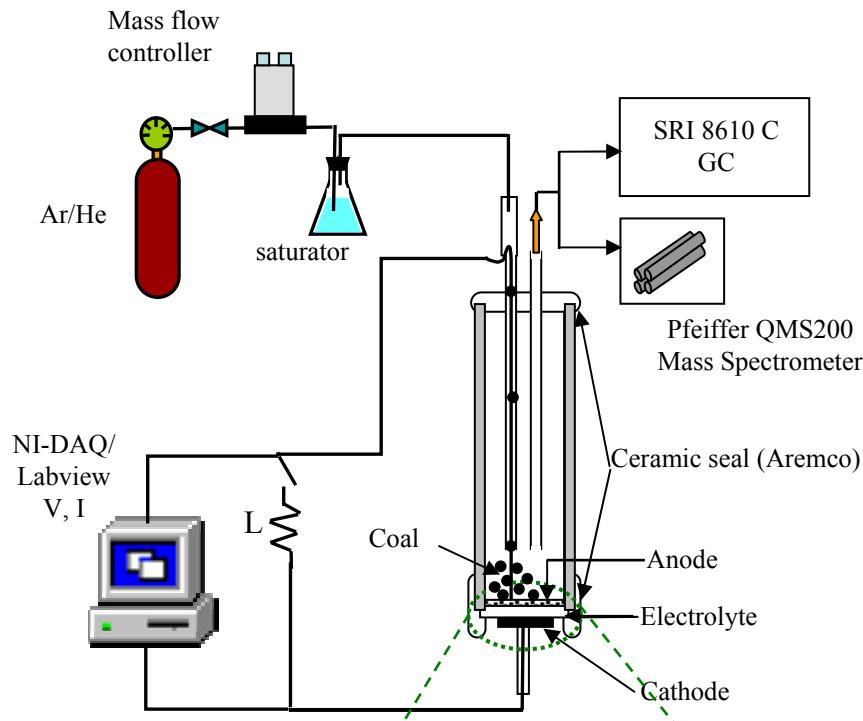


IR Spectra during Gasification of Ohio Coal # 5

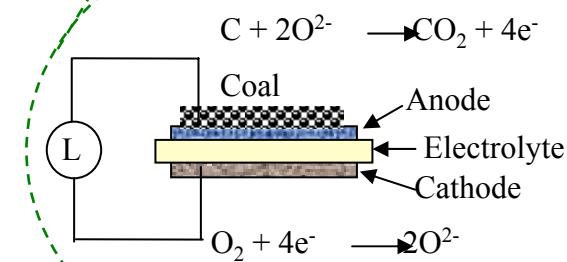


Testing Apparatus

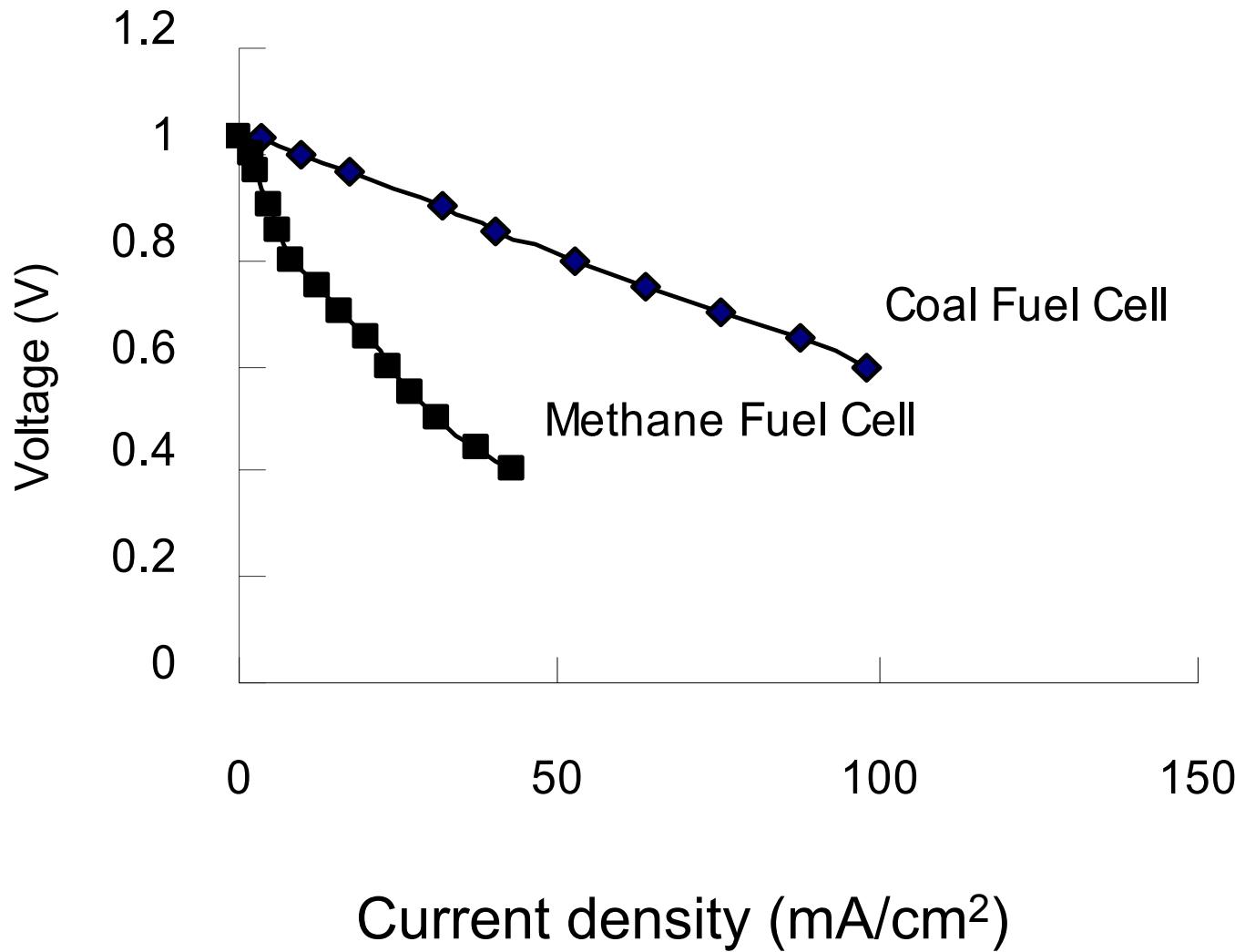
Picture of the fuel cell assembly



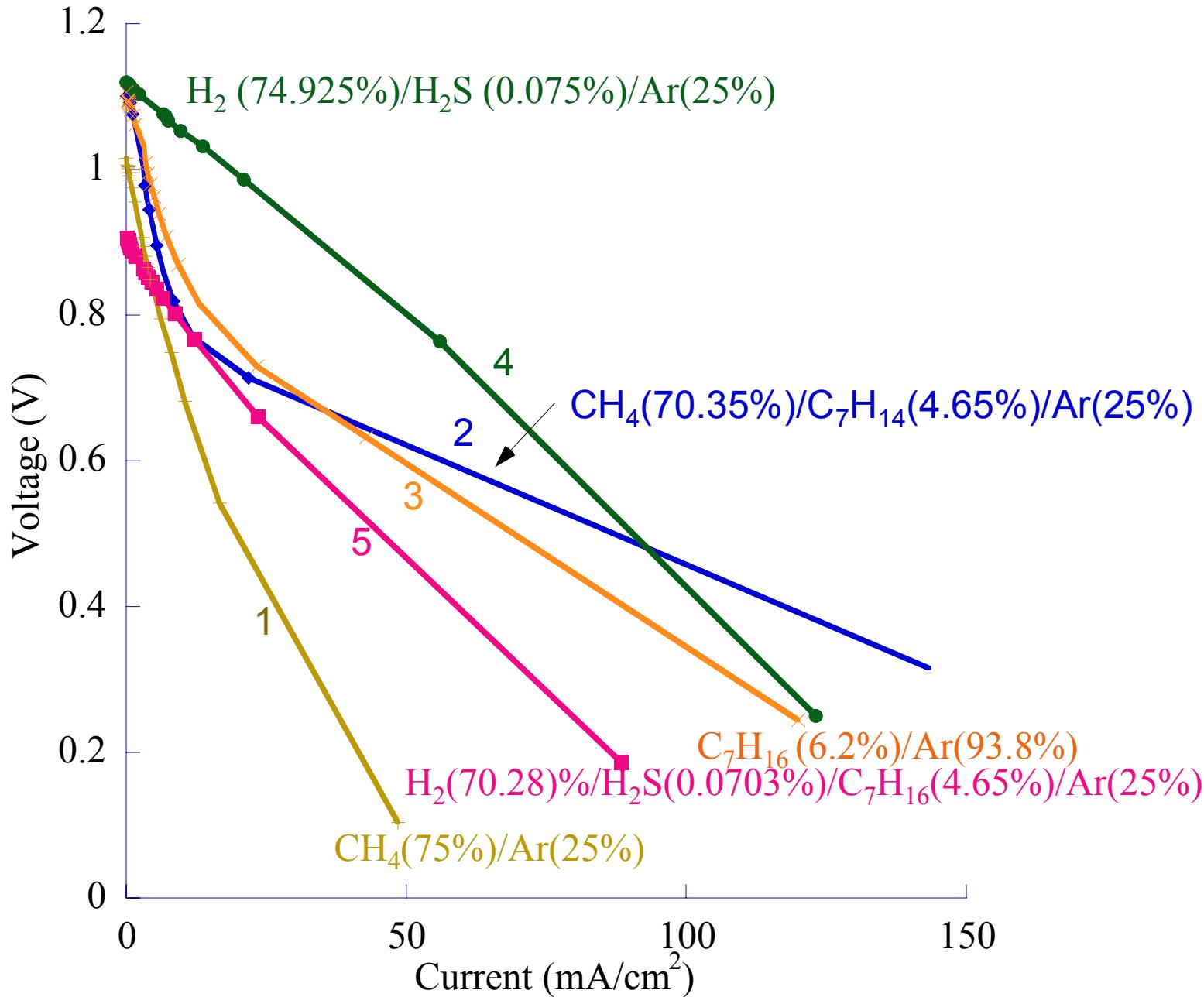
(2-b)



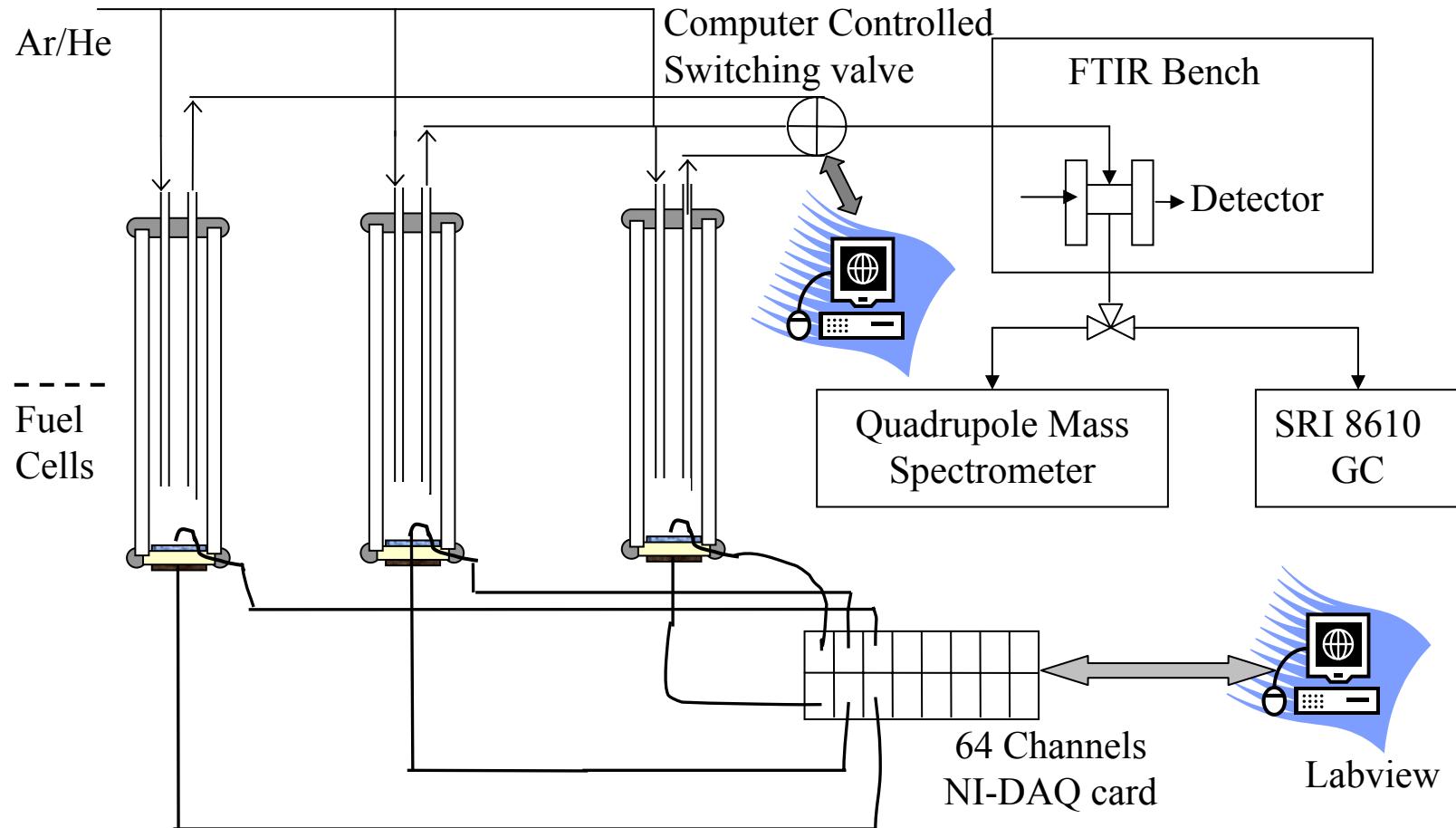
I-V Curves for CH₄ and Coal



V-I Curves of Different Fuels on Ni(5%)/Re(2%) catalyst



Combinatorial Catalyst Screening



Conclusions

- Power density: Coal > Coal gas > CH_4
- Fly ash produced from coal at 950 °C did not foul the anode catalyst surface.
- Future Tasks: Enhance the power density (mA/cm^2) by developing a highly active electrochemical oxidation catalyst and using thin electrolytes.

Acknowledgement: Rajesh Khatri and Rahul Singh